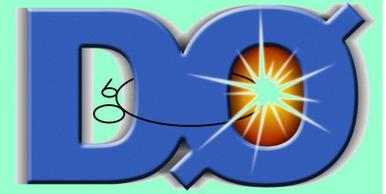




Top quark cross sections



Lars Sonnenschein



on behalf of the CDF and DØ collaborations

- Introduction
- Top pair cross sections
- Single top
- Conclusions and outlook

Tevatron at Fermilab

- Proton antiproton collisions
 $\sqrt{s} = 1.96 \text{ TeV}$
(Run I: 1.8 TeV)

- Linac upgrade

- Main injector
(150 GeV proton storage ring)

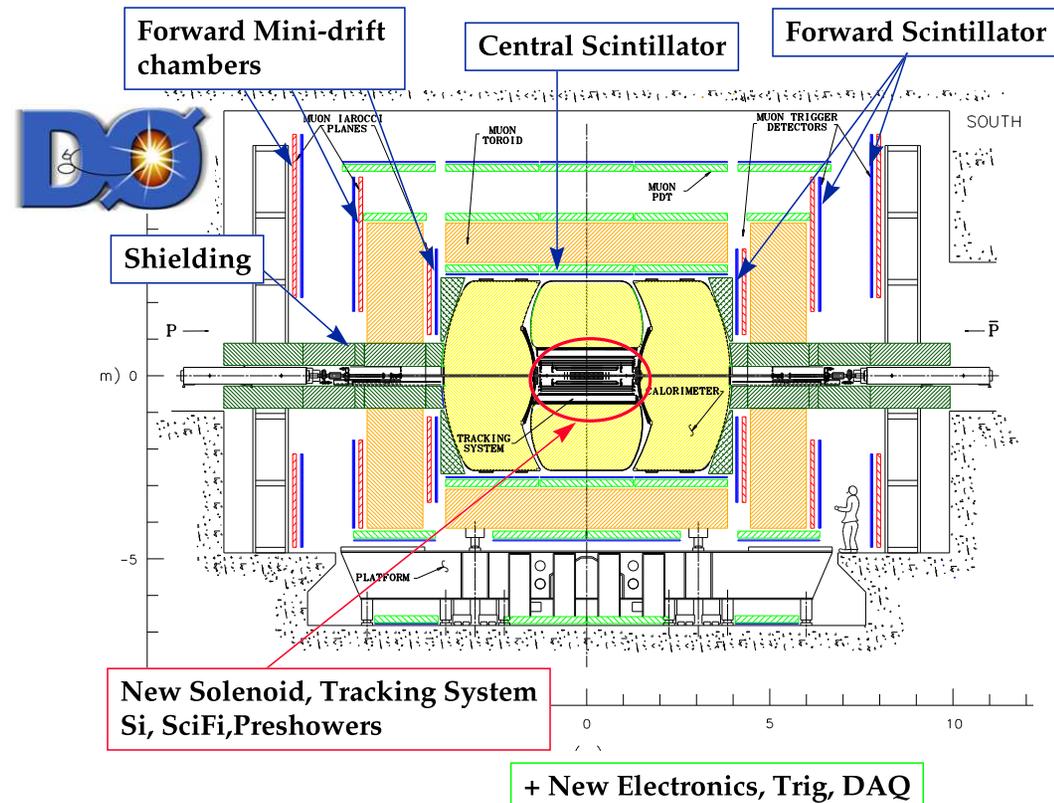
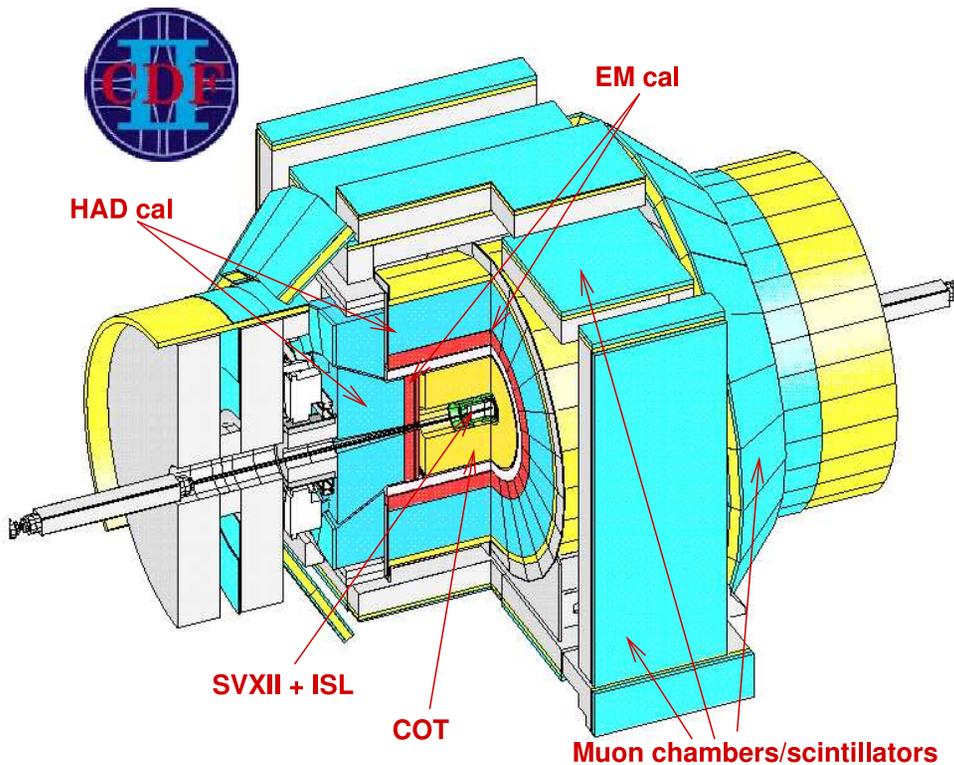
- antiproton recycler
+ electron cooling

- 36 bunches (396 ns spacing)

- Long term luminosity goals
(end of year 2009)
Base line: 4.4 fb^{-1}
Design: 8.5 fb^{-1}



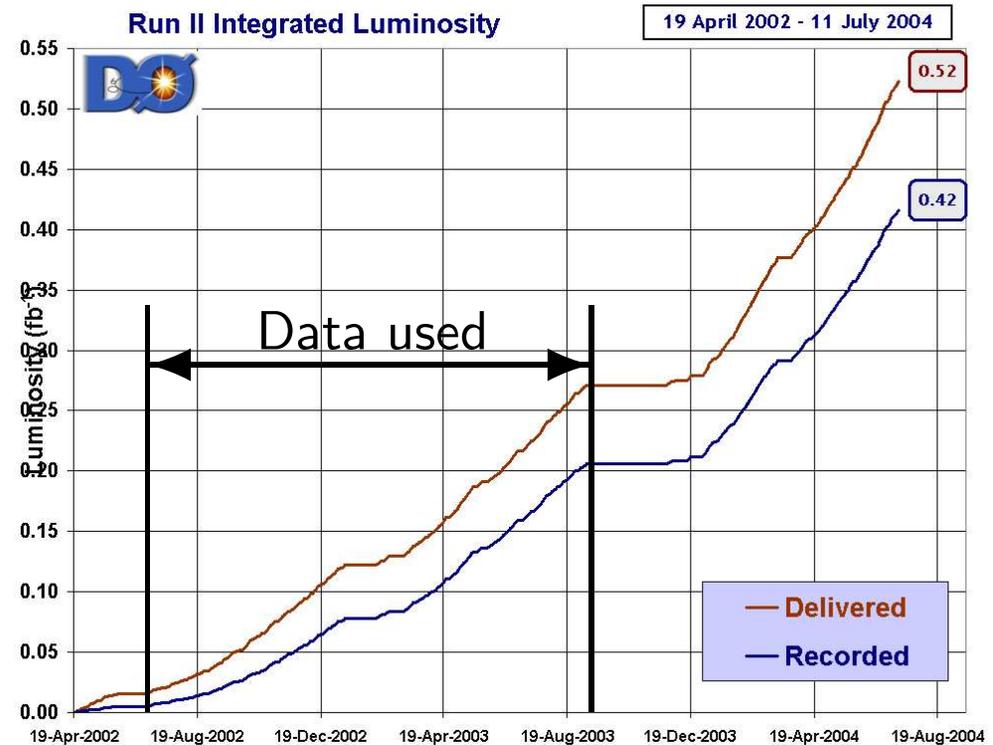
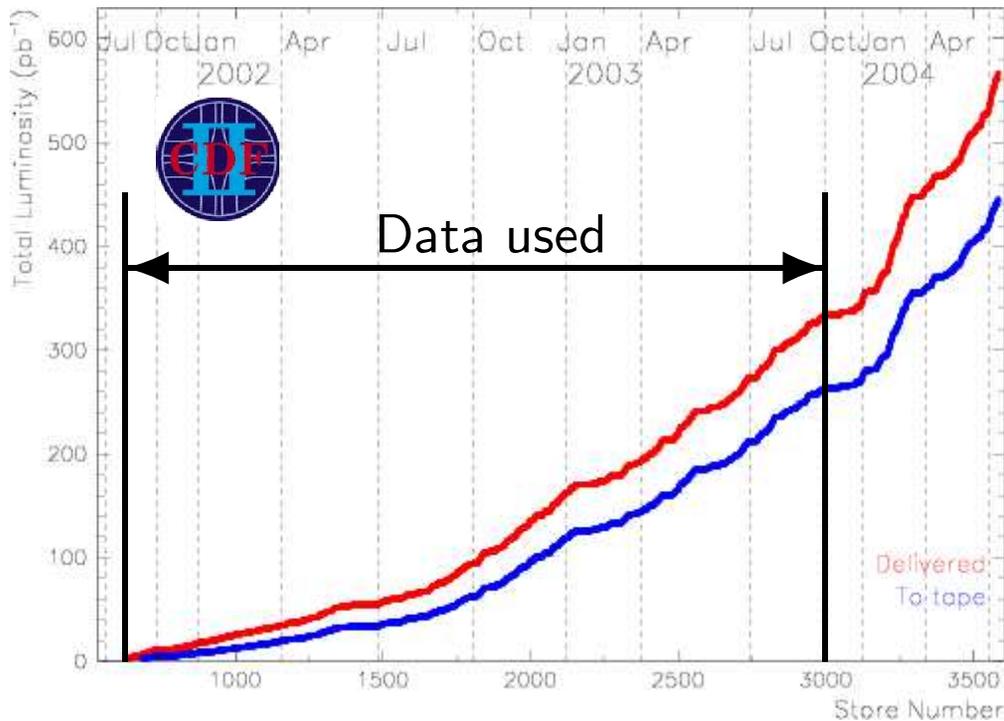
CDF and DØ in Run II



- Upgraded muon detectors
- New TOF detector
- New plug calorimeters
- New drift chamber
- New silicon tracking

- Upgraded muon coverage
- New tracking system
- New silicon tracker + trigger
- New solenoid
- New preshower

Run II performance and data samples

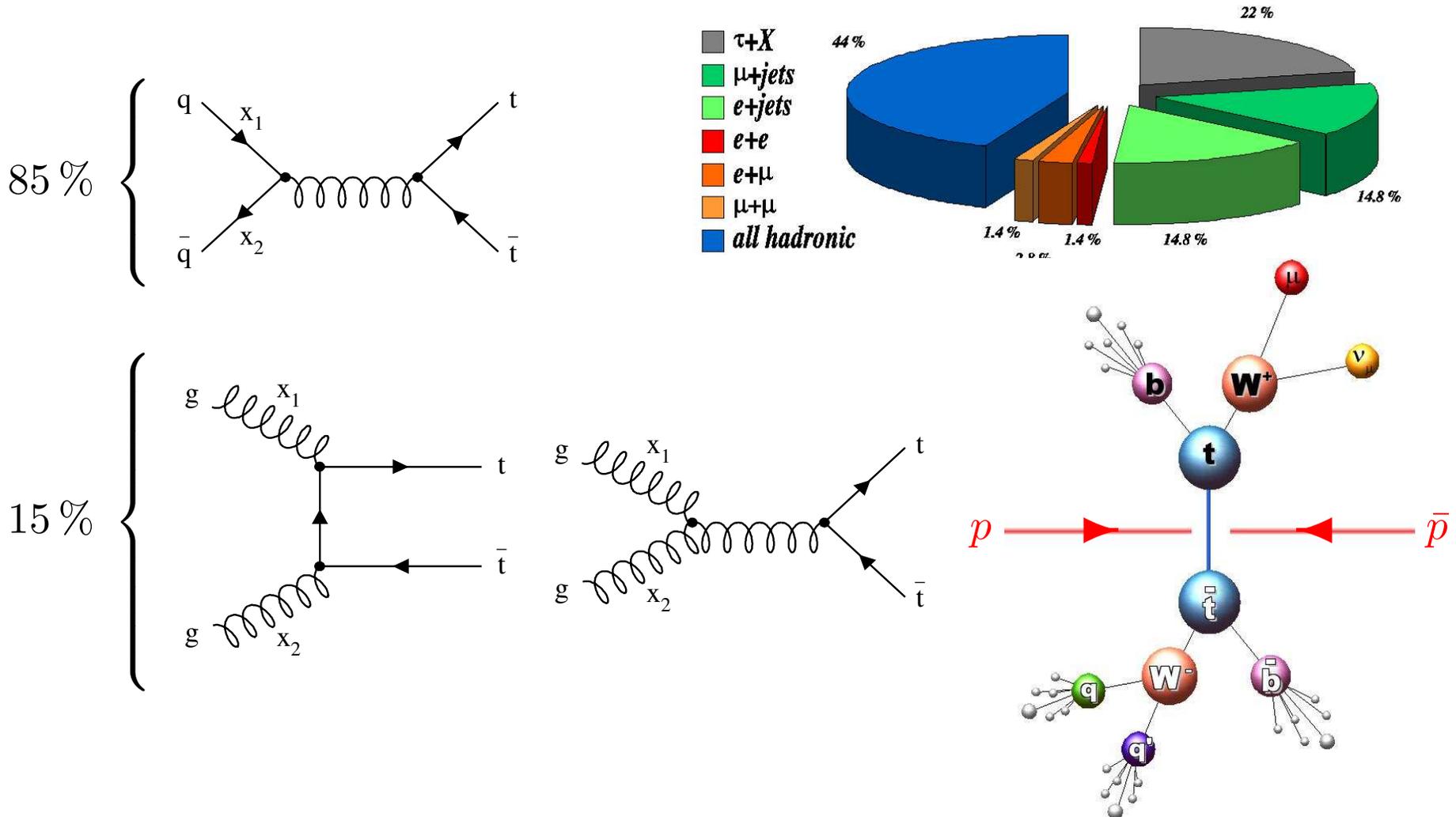


- Run II physics data taking started in July 2002
- Results are based on data taken until September 2003
(Analysis of subsequent data in progress)
- Analyses shown based on $140 - 200 \text{ pb}^{-1}$
(Run I: about 110 pb^{-1})

Top quark production and decay

At Tevatron ($\sqrt{s} = 1.96$ TeV) top quarks are primarily produced in pairs

$t \rightarrow Wb$ in $\sim 100\%$ of cases \Rightarrow final state determined by W decay





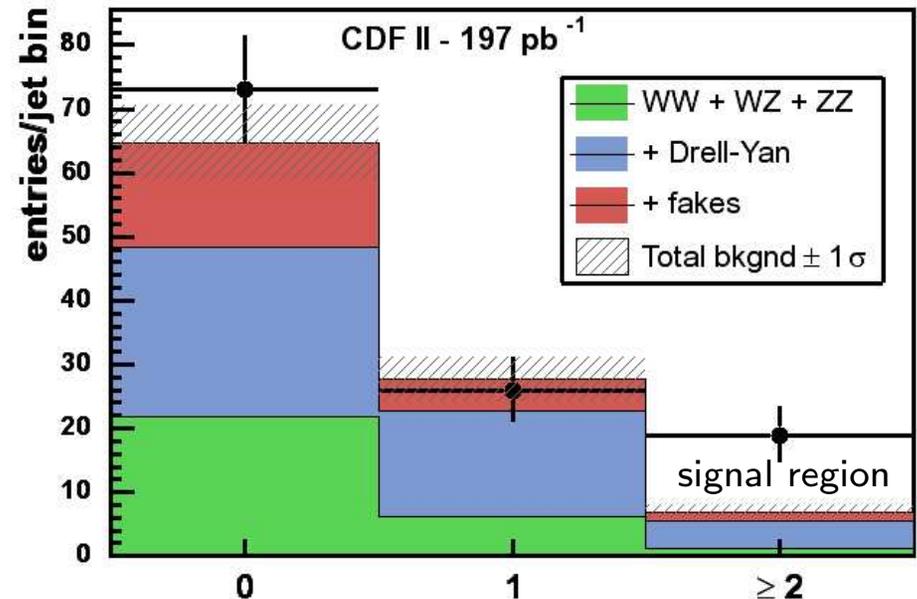
Top pair cross section: Dilepton channel



- Small branching ratio, relatively few SM backgrounds:
 - Drell-Yan, dibosons
 - \cancel{E}_\perp fakes
 - Isolated lepton fakes

- Preselection
 - Two opposite charged leptons (CDF optionally: second lepton may be loose, isolated high p_\perp track)
 - Two high p_\perp jets
 - Large \cancel{E}_\perp

Event count per jet bin

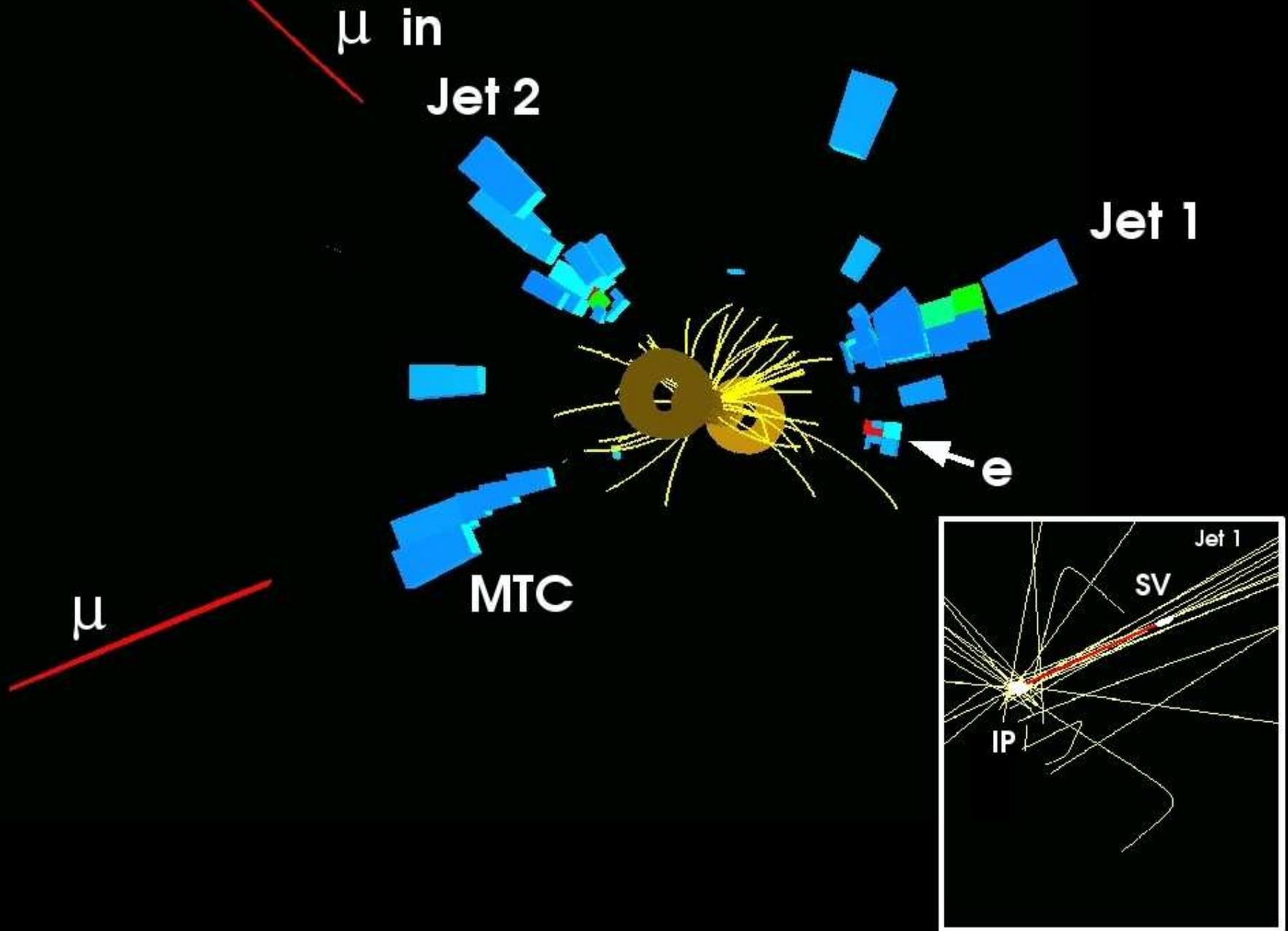


- $e\mu$ channel:
 - twofold $ee, \mu\mu$ branching ratio
 - no Drell-Yan $\rightarrow ll$ contribution

CDF	$\sigma(t\bar{t}) = 7.0_{-2.1}^{+2.4}(\text{stat})_{-1.1}^{+1.6}(\text{sys}) \pm 0.4(\text{lum}) \text{ pb}$	($\sim 200 \text{ pb}^{-1}$)
DØ	$\sigma(t\bar{t}) = 14.3_{-4.3}^{+5.1}(\text{stat})_{-1.9}^{+2.6}(\text{sys}) \pm 0.9(\text{lum}) \text{ pb}$	($\sim 140 \text{ pb}^{-1}$)



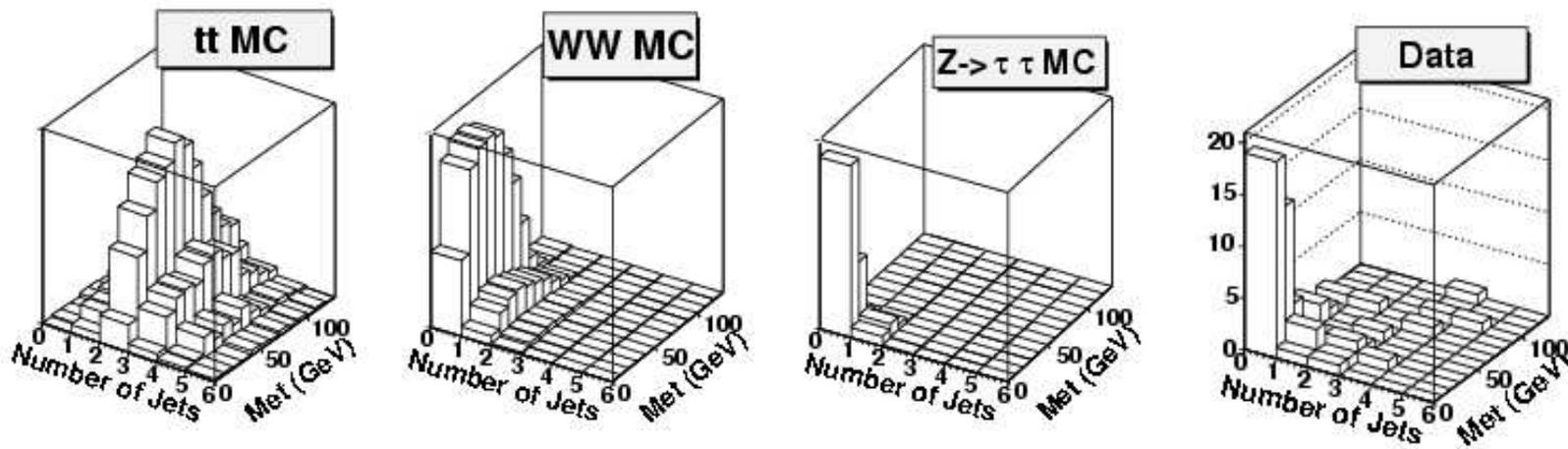
$t\bar{t} e\mu$ event candidate at DØ





$t\bar{t}$ dilepton inclusive analysis

- New CDF technique to measure $\sigma(t\bar{t})$ in dilepton inclusive channel
 - alternative approach to counting experiment
- No cuts other than two lepton requirement:
 - In case of same flavour: $Z \rightarrow ee, \mu\mu$ dominates
 - \Rightarrow Require significant \cancel{E}_\perp
- Fit data for $t\bar{t}$, WW , $Z \rightarrow \tau\tau$ contribution in two dimensional phase space ($\cancel{E}_\perp, N_{\text{jet}}$)



CDF II Preliminary

$e\mu$ space

CDF

$$\sigma(t\bar{t}) = 8.6^{+2.5}_{-2.4}(\text{stat}) + 1.1(\text{sys}) \text{ pb}$$

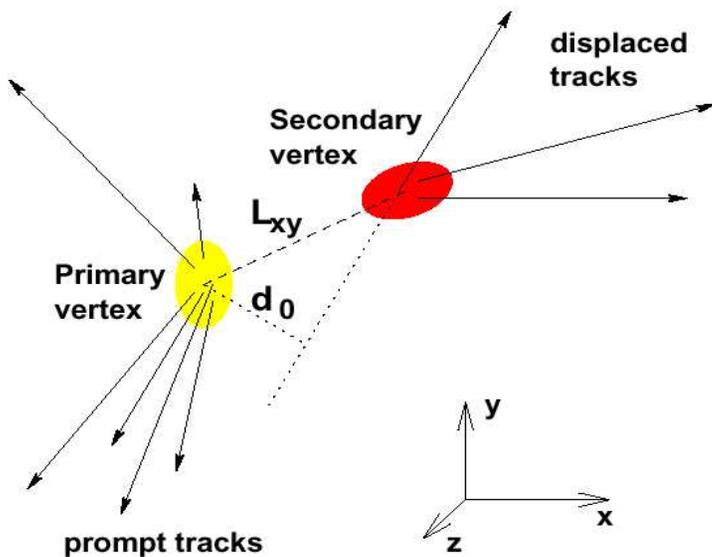
$$(\sim 200 \text{ pb}^{-1})$$



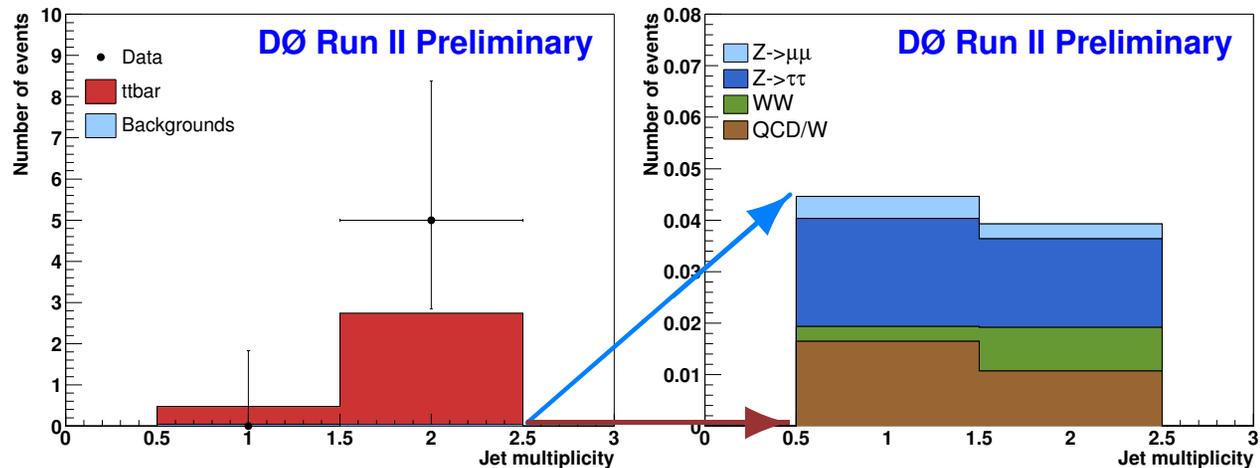
$t\bar{t}$ $e\mu$ channel analysis using b -tagging

- b -tagging
 - B hadrons have finite lifetime
 - travel mm's before decay
 - ⇒ exploit displaced tracks (JLIP, CSIP) secondary vertices (SVT) soft leptons from b decays (SLT)
 - Powerful background rejection

- New DØ analysis making use of a Secondary Vertex Tagger (SVX) after preselection cuts



Number of b -tagged events vs. jet multiplicity



DØ	$\sigma(t\bar{t}) = 11.1^{+5.8}_{-4.3}(\text{stat}) \pm 1.4(\text{sys}) \pm 0.7(\text{lum}) \text{ pb}$	$(\sim 160 \text{ pb}^{-1})$
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Top pair cross section: Lepton + Jets channel

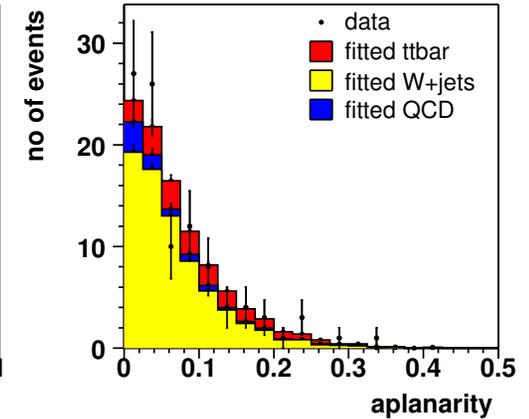
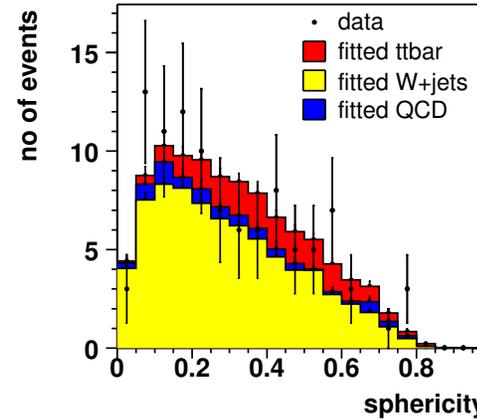


- Large branching ratio, SM backgrounds:
 - $W + \text{jets}$
 - Multijets: one jet faking lepton, \cancel{E}_\perp from mismeasured jet energies

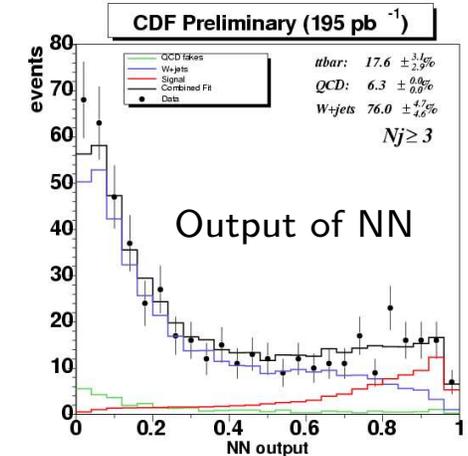
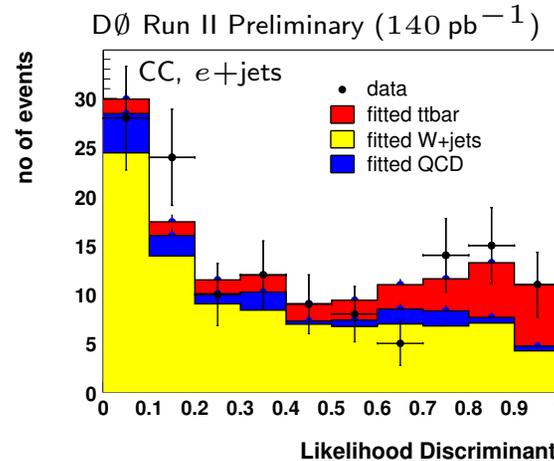
- Preselection
 - One charged high p_\perp lepton
 - Four high p_\perp jets
 - Large \cancel{E}_\perp

- Topological analysis
 - Choice of variables: maximal significance, minimal JES dependence
 - Likelihood Discriminant
 - Kinematic fit to data

Topological variables



Likelihood discriminant



$e + \mu$	CDF	$\sigma(t\bar{t}) = 6.7 \pm 1.1(\text{stat}) \pm 1.6(\text{sys}) \text{ pb}$	(195 pb^{-1})
combined	DØ	$\sigma(t\bar{t}) = 7.20_{-2.39}^{+2.58}(\text{stat})_{-1.68}^{+1.57}(\text{sys}) \pm 0.47(\text{lum}) \text{ pb}$	$(\sim 140 \text{ pb}^{-1})$



$t\bar{t}$ muon + jets channel analysis using b -tagging

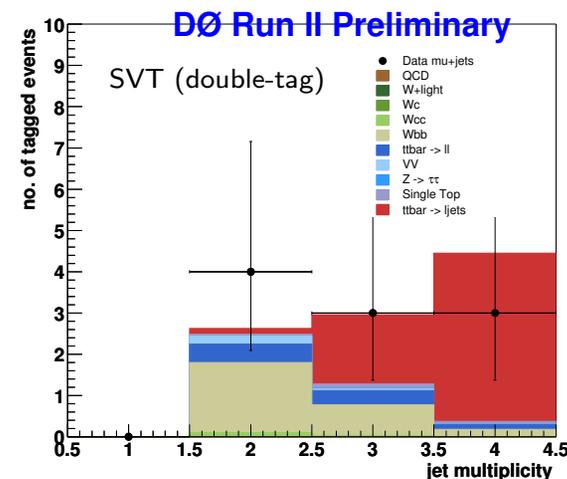
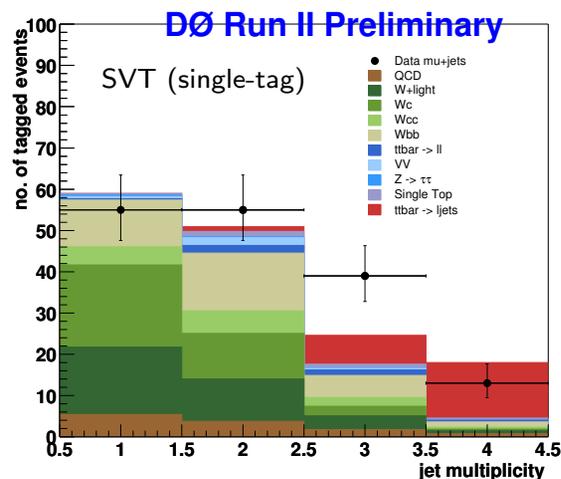
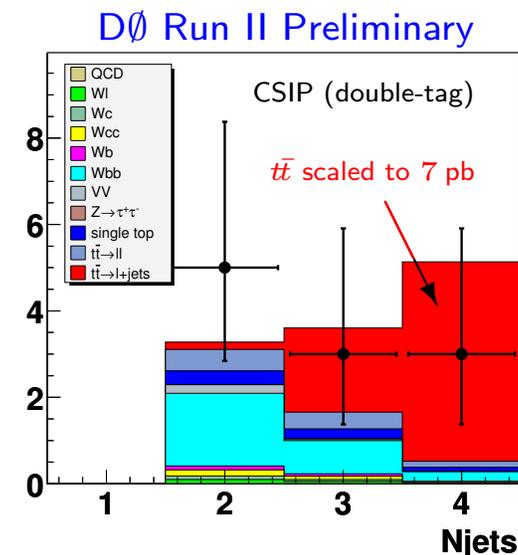
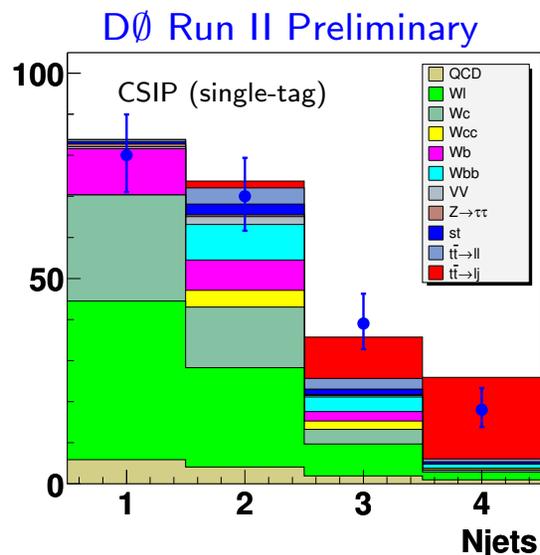
- New DØ analysis making use of CSIP and SVT b -taggers

 - Counting experiment

 - b -tagging enhanced significance

 - Maximum likelihood fit to observed number of events

 - Subdivided analysis:
 - one jet tagged (single-tag)
 - both jets tagged (double-tag)
- Results combined



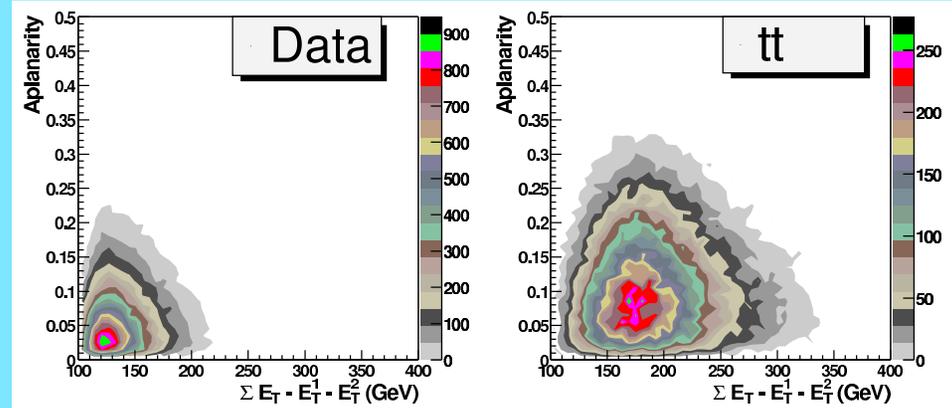
DØ (CSIP)	$\sigma(t\bar{t}) = 5.2_{-1.5}^{+1.7}(\text{stat})_{-1.2}^{+1.7}(\text{sys}) \text{ pb}$	($\sim 160 \text{ pb}^{-1}$)
DØ (SVT)	$\sigma(t\bar{t}) = 6.9_{-1.7}^{+1.9}(\text{stat})_{-1.7}^{+1.9}(\text{sys}) \text{ pb}$	($\sim 160 \text{ pb}^{-1}$)



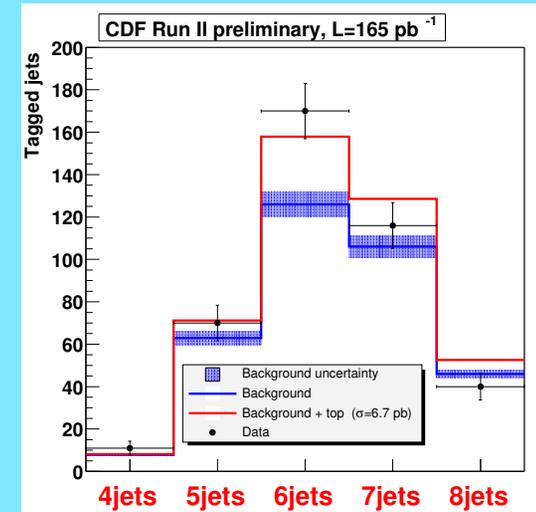
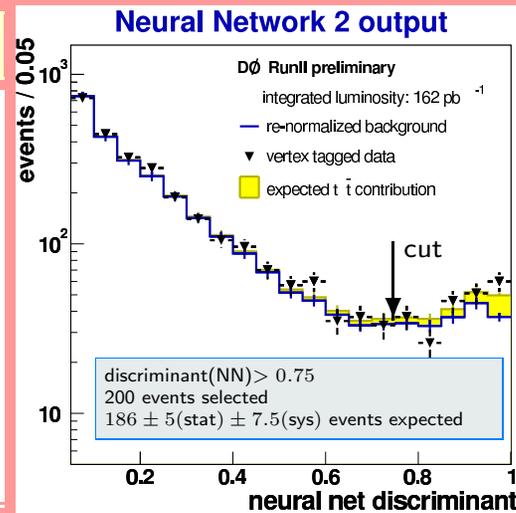
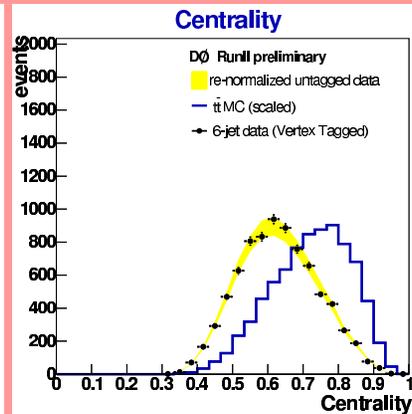
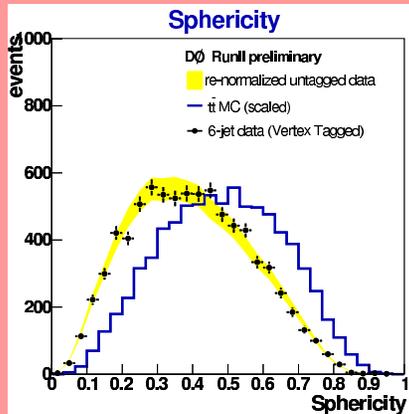
Top pair cross section: All-Hadronic channel

- Largest branching fraction,
 - Multijet background $\sim 10^3 \times$ larger
- Increasing significance by
 - Topological cuts
 - b -tagging
 - Veto against
 - Isolated leptons
 - Poorly reconstructed primary vertex

CDF: Count double b -tagged events in $6 < N_{\text{jets}} < 8$ bin



$D\phi$: Count single b -tagged NN-discriminant enhanced events



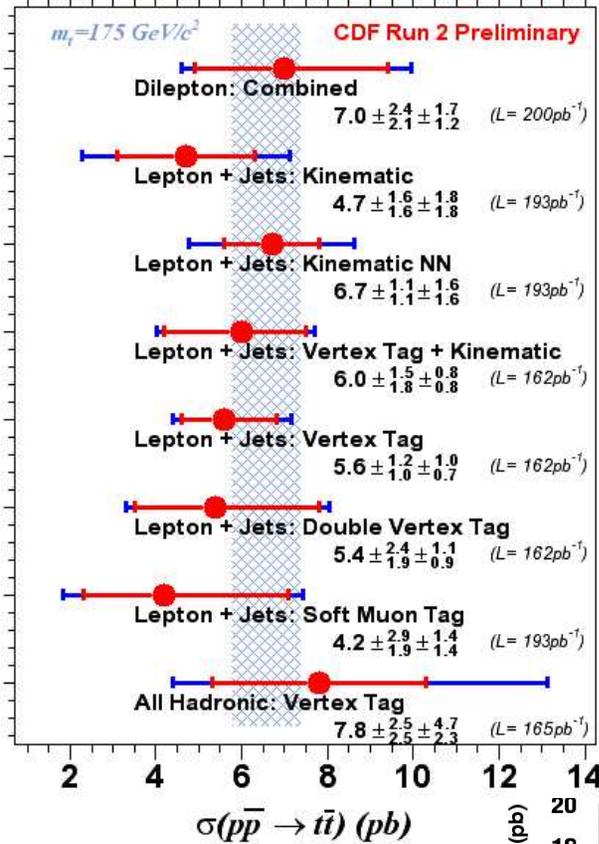
CDF	$\sigma(tt) = 7.8_{-1.0}^{+2.5}(\text{stat})_{-2.3}^{+4.7}(\text{sys}) \text{ pb}$	$(\sim 165 \text{ pb}^{-1})$
$D\phi$	$\sigma(tt) = 7.7_{-3.3}^{+3.4}(\text{stat})_{-3.8}^{+4.7}(\text{sys}) \pm 0.5(\text{lum}) \text{ pb}$	$(\sim 160 \text{ pb}^{-1})$



Top pair cross section summary



Top Pair Production Cross Section

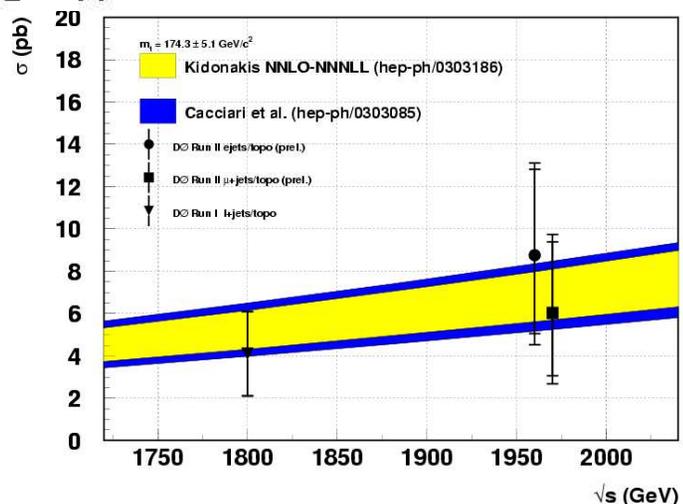
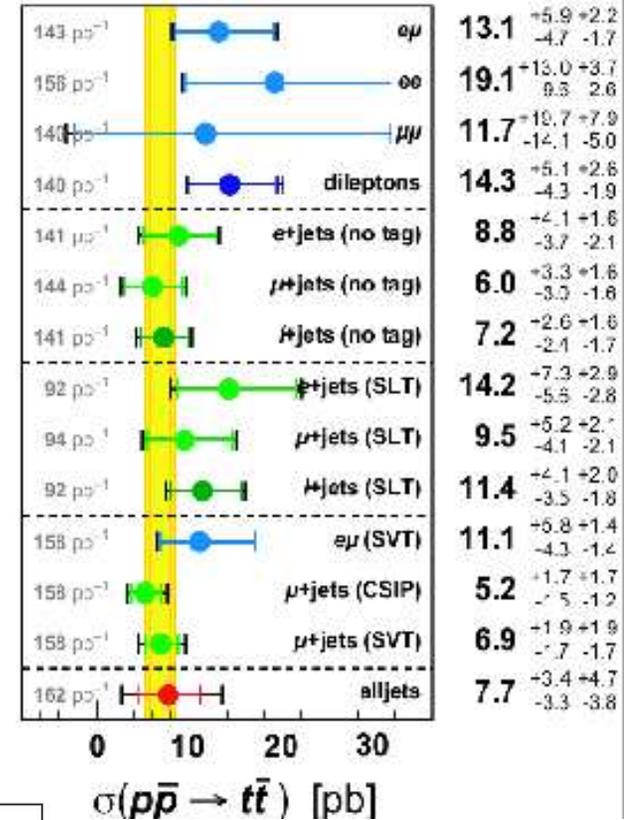


Observed cross sections consistent with each other and with the SM prediction for $m_t = 175 \text{ GeV}/c^2$:

$$\sigma(tt) = 6.7^{+0.7}_{-0.9} \text{ pb}$$

Bonciani *et al.*, *Nucl. Phys.* B529, 424 (1998)
 Kidonakis and Vogt, *Phys. Rev.* D68, 114014

DØ Run II Preliminary

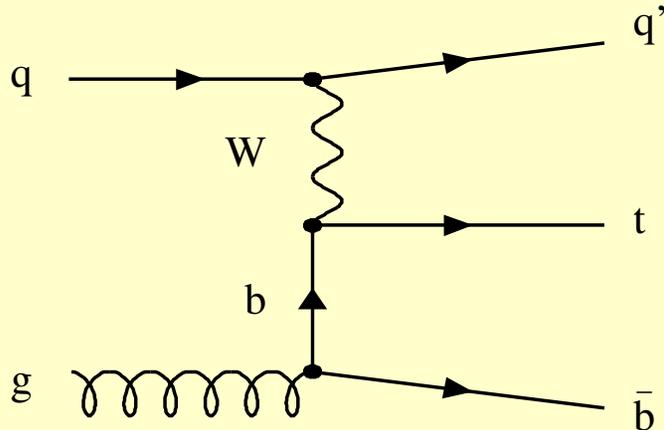




Tevatron search for single top quark production



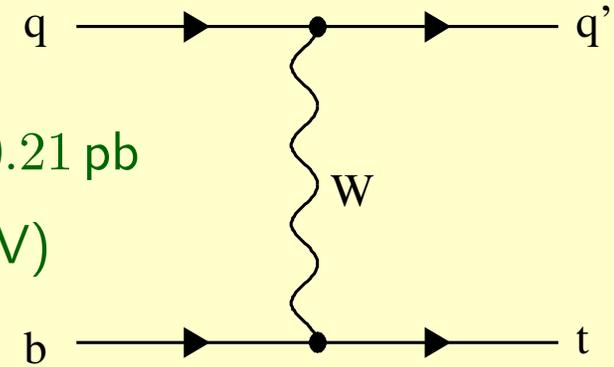
Single top cross sections have same order of magnitude than $t\bar{t}$



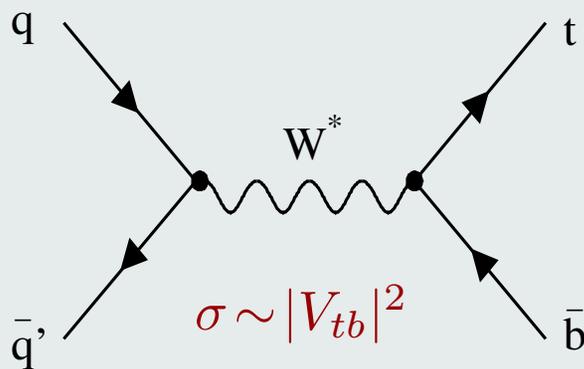
t-channel

$$\sigma_t^{NLO} = 1.98 \pm 0.21 \text{ pb}$$

(at $\sqrt{s} = 1.96 \text{ TeV}$)



Run I limits ($\sqrt{s} = 1.8 \text{ TeV}$): $\sigma < 22 \text{ pb}$ (DØ), $\sigma < 13 \text{ pb}$ (CDF)



s-channel

$$\sigma_t^{NLO} = 0.88 \pm 0.07 \text{ pb}$$

(at $\sqrt{s} = 1.96 \text{ TeV}$)

$$\sigma \sim |V_{tb}|^2$$

Run I limits ($\sqrt{s} = 1.8 \text{ TeV}$): $\sigma < 17 \text{ pb}$ (DØ), $\sigma < 18 \text{ pb}$ (CDF)

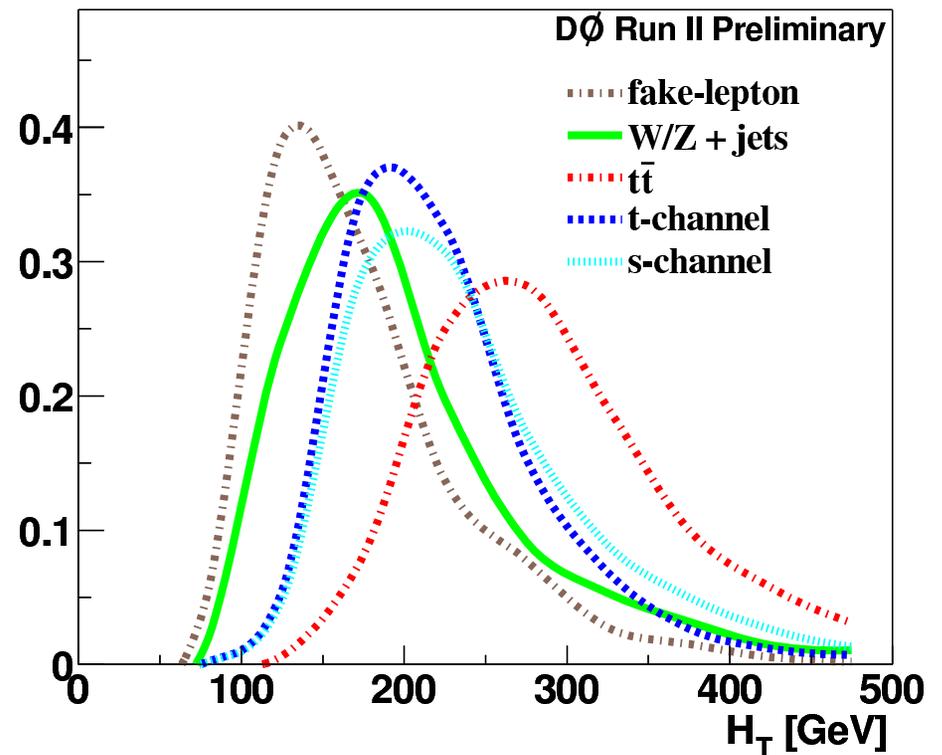
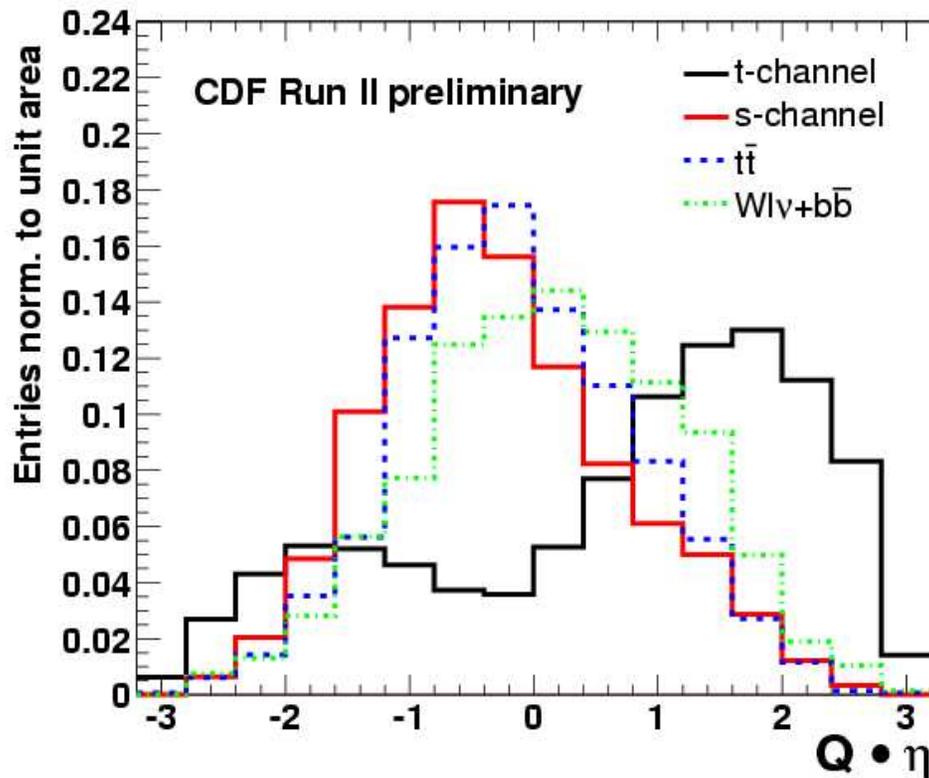


Single top quark in Run II



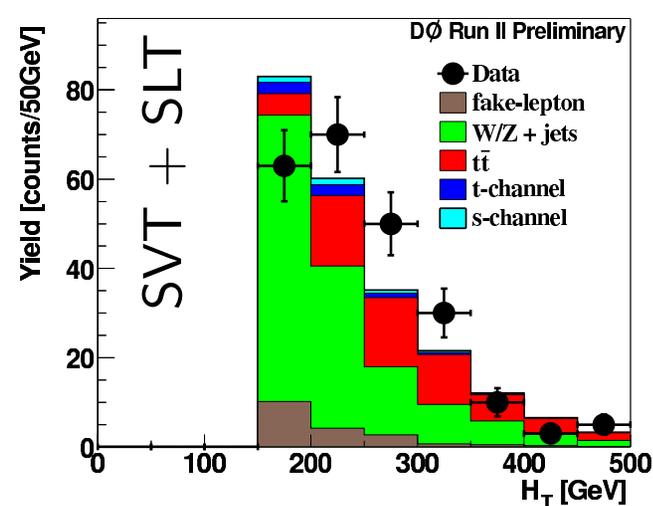
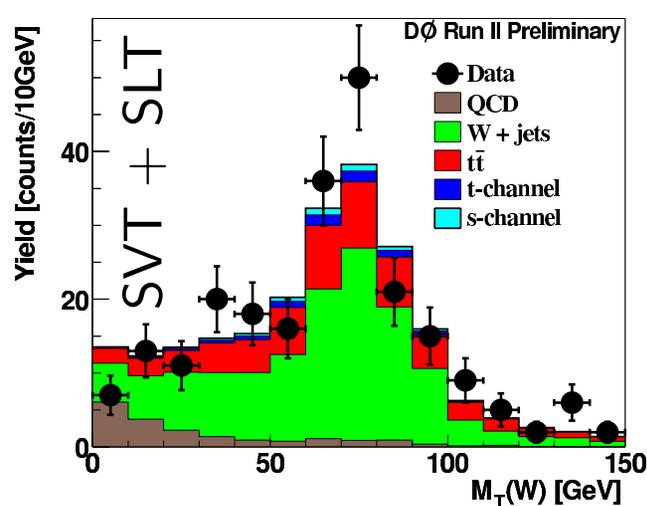
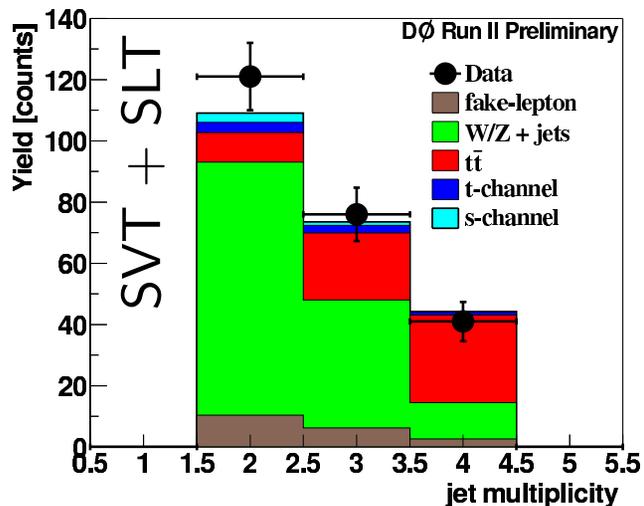
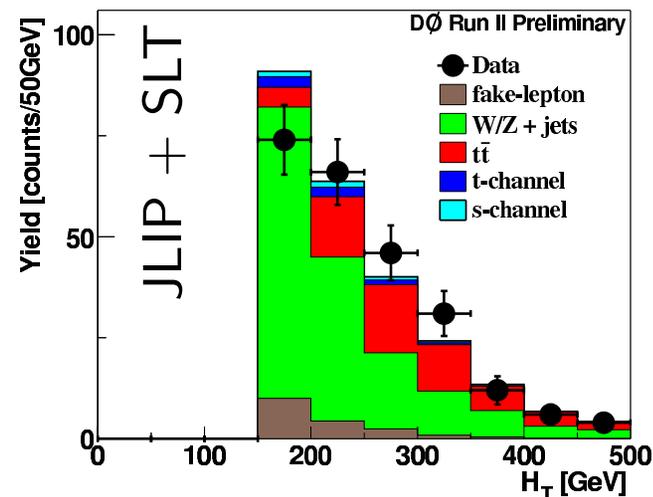
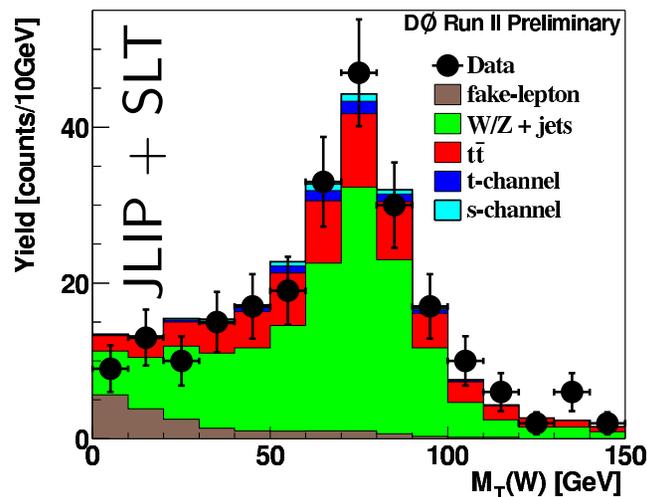
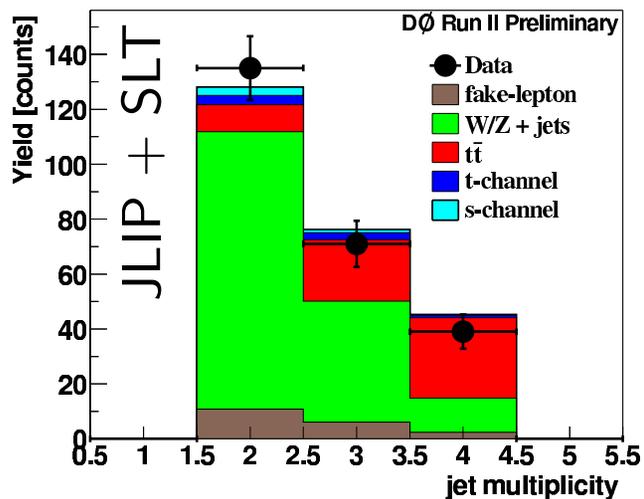
- Signature and selection:
 - One isolated high p_{\perp} lepton
 - Large \cancel{E}_{\perp}
 - Two high p_{\perp} jets (at least one b -tagged)

- Background
 - Large non top background (predominantly W +jets)
 - Misidentified $t\bar{t}$
 - \Rightarrow Not a simple counting experiment





Data distributions compared to SM prediction



Good agreement between data and MC

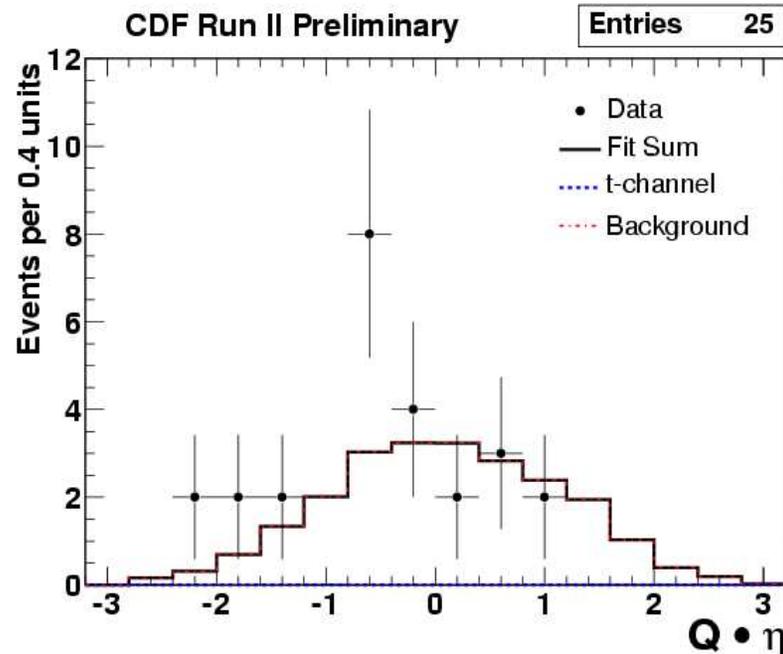
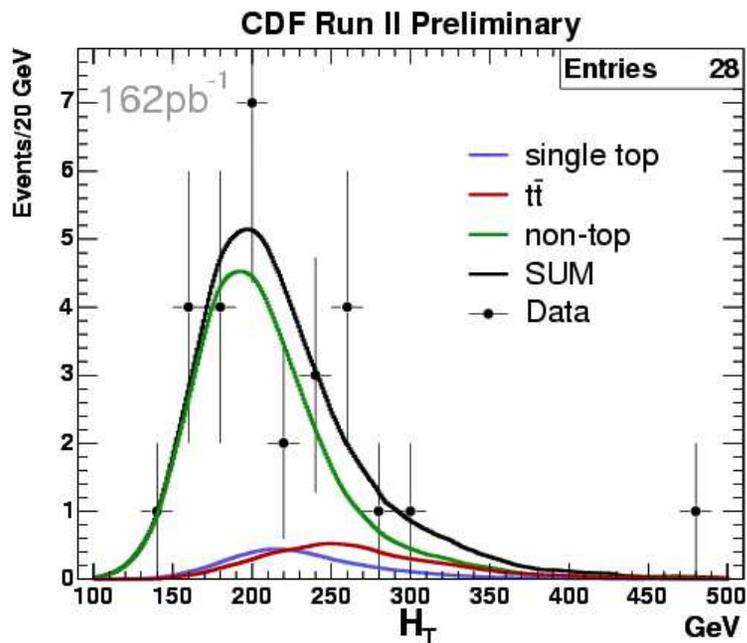
(no MC error bars are shown)



Tevatron Run II single top quark cross sections



Maximum likelihood fit to data distributions

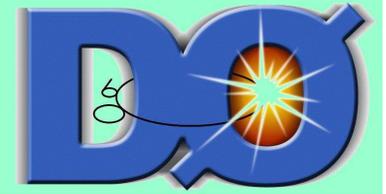


Cross sections	<i>s</i> -channel	<i>t</i> -channel	<i>s</i> + <i>t</i> -channel	\mathcal{L}
SM prediction (NLO)	$\sigma = 0.88 \text{ pb}$	$\sigma = 1.98 \text{ pb}$	$\sigma = 1.86 \text{ pb}$	—
CDF (@ 95% C.L.)	—	$\sigma < 8.5 \text{ pb}$	$\sigma < 13.7 \text{ pb}$	160 pb^{-1}
DØ (@ 95% C.L.)	$\sigma < 19 \text{ pb}$	$\sigma < 25 \text{ pb}$	$\sigma < 23 \text{ pb}$	$156 - 169 \text{ pb}^{-1}$

Observation expected with about 2 fb^{-1}



Conclusions and outlook



- Top is re-established in Run II at CDF and DØ
- Consistent $t\bar{t}$ cross section measurements
- Expect single top discovery with about 2 fb^{-1}
- More data to be analyzed is on the way
- Refinement of analyses is in progress